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ARTICLE

A prospective study of health behaviors and risk of all-cause and cause-specific mortality after spinal cord injury

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Abstract

Study design Prospective cohort study

Objectives Identify the association between health behaviors and risk of all-cause and cause-specific mortality in adults with chronic spinal cord injury (SCI)

Setting A large rehabilitation hospital in the Southeastern United States.

Methods Participants included 3070 adults (>18 years old) with chronic (>1-year) traumatic SCI. Behavioral data were collected by mail-in self report assessment between 1997–1998 and 2007–2010. Mortality status was determined using the National Death Index as of December 2016. We examined the associations between six behavioral domains (prescription medication usage, alcohol use, smoking, two nutrition factors, and fitness) and risk of all-cause and cause-specific mortality, including deaths due to sepsis (ICD-10-CM A40-A41), pneumonia and influenza (J09-J18), cancer (C00-D49), heart and blood vessel diseases (I00-I99), unintentional injuries (V01-X59, Y40-Y84, Y88), and all other causes.

Results All health behaviors, except one nutrition factor, were associated with risk of all–cause mortality. Prescription medication usage was related to an increase in the risk of deaths caused by sepsis, unintentional injuries, and other causes of death. Alcohol usage was associated with an increased hazard of deaths due to unintentional injuries. Smoking was associated with increased risk of deaths due to cancer, heart and blood vessel diseases, and all other causes. Fitness level was protective from deaths due to heart and blood vessel diseases and other causes, as was the other nutrition factor.

Conclusions The results identify relationships between health behaviors and specific causes of death and affirm their importance as targets for SCI rehabilitation research and intervention.

Introduction

Despite dramatic improvements in acute survival [1–3], individuals with chronic (>1 year) spinal cord injury (SCI) have an increased risk of early mortality compared to the general population [2–5]. Mortality rates for those with chronic SCI have not improved since the 1980s and continue to increase as the population ages [3, 4, 6]. A substantial body of mortality research has identified risk factors and specific causes of death that contribute to the reduced life expectancy.

Most studies have focused on risk factors for mortality and have been limited to all-cause mortality and the demographic and injury characteristics influencing survival [7–12]. Injury severity, specifically higher neurologic level and more severe neurologic impairment, older age, and etiology of injury are associated with increased risk of mortality [5, 13, 14]. The disparities in survival related to SCI characteristics become more apparent over time [13]. There is a need to investigate modifiable risk factors that may contribute to cause-specific mortality.

A growing body of research has linked health behaviors, one potential set of modifiable risk factors, to all-cause mortality and unintentional deaths. According to the multistage *Theoretical Risk and Prevention Model (TRPM)* [8, 15], risk and protective health behaviors are significantly predictive of mortality, above and beyond the basic demographic and injury characteristics [16–19]. In addition, health behaviors are predictive of health conditions [20–22], the risk factors most predictive of mortality in the model [8]. Similar to the general population [23], the identified health risk behaviors associated with mortality include smoking [17–19, 24, 25],

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prescription medication usage [11, 16–18, 26], and binge drinking [11, 16–18]. Healthy nutrition and fitness/physical activity level are generally protective from mortality after SCI [17, 19]. Despite these previously identified associations, little is known about why these behaviors influence life expectancy or which specific causes of death they may most greatly influence. Due to their influence on both morbidity and mortality, these potentially *modifiable* health behaviors represent a target area for future research and intervention to reduce specific causes of death.

It is essential to determine how behavioral factors relate to the leading causes of death among those with chronic SCI, moving beyond basic demographic and SCI characteristics to apply more efficient and targeted interventions to specific causes. Among those with SCI, the leading causes of death include diseases of the respiratory system, infectious and parasitic disease, cancer, hypertensive and ischemic heart disease, other heart disease, and unintentional injuries [4]. Respectively, pneumonia and sepsis/septicemia are the primary cases associated with respiratory and infectious causes [4]. Excluding studies focused on single specific causes (e.g., unintentional death or suicide), limited data exist on health behaviors as predictors of cause-specific mortality after SCI.

Our purpose was to identify the associations between specific health behaviors and all-cause and cause-specific mortality. The objectives were to investigate (1) whether previously identified health behaviors, including prescription medication usage, alcohol use, smoking, nutrition, and fitness are predictive of all-cause mortality, and (2) the impact of each health behavior on specific causes of death (sepsis, pneumonia and influenza, cancer, heart and blood vessel diseases, unintentional injuries, and other causes). This study builds upon previous research [17, 27] by determination of *competing risk* of mortality using health behaviors identified within the same prospective cohort study, with the addition of a second cohort to more than double the sample size.

Methods

Participants

Prior to initiating this prospective study, human experimentation was approved by the local institutional review board. Participants were identified through records at a large specialty hospital in the Southeastern United States. The inclusion criteria at enrollment were: (1) traumatic SCI, (2) minimum of 1-year post-injury, and (3) 18 years or older. Two participant cohorts were utilized [28]; the first cohort was enrolled between 1997 and 1998 ($n = 1386$) and the second was enrolled between 2007 and 2009 ($n = 1684$) with a total of 3070 participants (Fig. 1). Longitudinal data were collected for the first cohort at time 2. The final study sample was 2979 after removing 46 ineligible participants and 45 participants missing key time information.

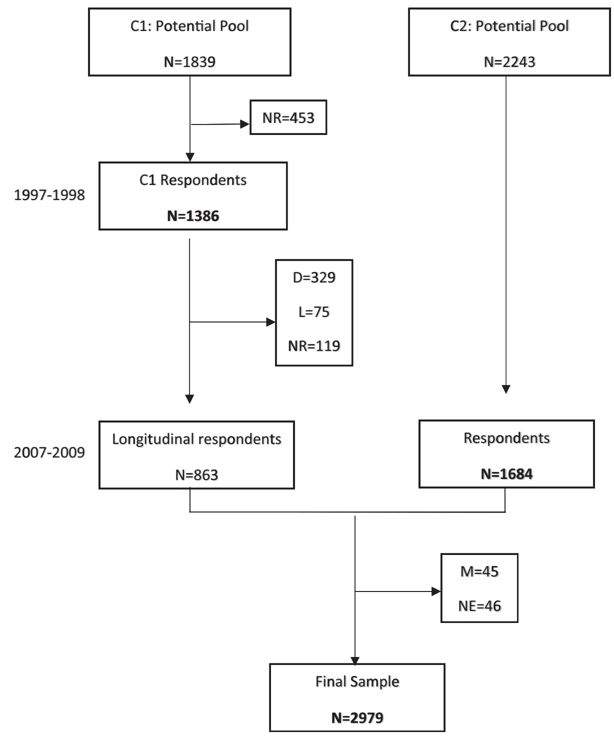

Fig. 1 Flow chart of participants. C1: Cohort 1, C2: Cohort 2, D: deceased by the time of the next follow-up (no further participation), L: lost to follow-up (could not be found—no further participation), M: missing or incomplete data NR: non-respondents, NE: not eligible, NFC: requested no further contact

Procedures

This study was designed to follow the TRPM and specifically identify risk and protective factors for adverse health outcomes, secondary health conditions, chronic health conditions, utilization of health services (e.g., hospitalizations) and, consistent with the focus of the current manuscript, all-cause and cause-specific mortality. The data used to identify risk and protective factors for mortality were from the first two stages of data collection. We utilized similar data collection procedures at each of the two times of measurement, with the exception that participant remuneration increased from \$20 in 1997–1998 to \$50 in 2007–2009. Before sending the self-report assessment to prospective participants, we first mailed a cover letter describing the study and alerting them that materials would arrive 4–6 weeks later.

Mortality status was determined using the National Death Index (NDI) of the National Center for Health Statistics [29]. All records were submitted to the NDI in January 2018, and mortality status was determined as of December 31, 2016. There is an approximate 16- to 18-month lag between the end of the calendar year and the availability of the data set for determining mortality from the NDI. The NDI *plus* service provided the ICD-10-CM codes for the underlying cause of death (UCD) and up to 20 contributing causes. Considering previous research and the leading causes of death, we classified the deceased into six categories based on UCD: sepsis (A40-A41), pneumonia and influenza (J09-J18), cancer (C00-D49), heart and blood vessel diseases (I00-I99), unintentional injuries (V01-X59, Y40-Y84, Y88), and all other causes. If a UCD was listed as either "Paraplegia and quadriplegia," (G82) or "Other and unspecified diseases of spinal cord" (G95), we reassigned the decedent's UCD based on one of the up to 20 multiple causes, based on clinical judgment. Two independent experts classified causes of death in these cases ($n = 71$), and a third expert made the final selection in cases where there was disagreement ($n = 27$).

Measures

The primary variables of interest included six health behavior factors including: prescription medication usage, alcohol use, smoking, two nutrition factors, and fitness identified in previous research. In 2009, Krause et al. [27] identified these six factors as *SCI health behaviors* via exploratory and confirmatory factor analysis. The seventh factor from the initial study, *SCI healthy activities*, was not used because it was only included in the baseline SRA administered to the 1997–1998 cohort and subsequently dropped because it appeared to reflect behaviors in response to health problems, rather than the intended preventative measures (e.g., pressure release used after individuals developed pressure ulcers). Additionally, we did not measure "smoking in bed" at the second time of measurement, so we removed this indicator from the smoking factor.

The first factor, *prescription medication usage*, included medication usage frequency for treating pain, spasticity, depression, and sleep problems; the *alcohol* factor was comprised of number of days consuming alcohol, number of days binge drinking, and CAGE score [30]; the *smoking* factor had two indicators, regular smoking and number of cigarettes smoked per day; the *nutrition—1* factor (mostly healthy nutrition practices) reflected drinking juices, eating fruit, salad, carrots, vegetables, and breakfast; *nutrition—2* factor (mostly unhealthy options) reflected eating fried food, red meat, junk food, and adding salt to food; the *fitness* factor measured planned exercise, exercise compared to others with SCI, overall fitness, and overall lifestyle. The detailed measurement information for each factor, including specific question phrasing from the self-report assessment and results from the factor analysis can be found in the earlier study [27]. We standardized each indicator and used z scores to make the composite score for all health behavior factors.

In addition to the health behavior factors, we assessed basic demographic and injury related data. We measured sex, age at injury, and years post-injury. Race/ethnicity was measured by three categories: non-Hispanic White, non-Hispanic Black, and others. Injury severity was grouped into four categories: cervical level C1-C4, non-ambulatory; cervical level C5-C8, non-ambulatory; non-cervical, non-ambulatory; and all ambulatory regardless of injury level. Participants were asked, "For someone of your height, would you currently classify yourself as underweight, a bit underweight, average weight, a bit overweight, or overweight?" We combined the middle three responses, "a bit underweight, average weight, a bit overweight," as one category to make the co-variate of weight status. For individuals in cohort 1 who participated at both time 1 and time 2 ($n = 863$), we used their most recent response. If they had a missing response, we used their time 1 measure as the replacement.

Analyses

All analyses were conducted using SAS software version 9.4. We completed bivariate analyses comparing survivors and the deceased on demographic, injury characteristics, weight status, and the six health behavior factors. We used a univariate Cox model to test whether those factors have a significant impact on mortality.

In the survival analyses, all decedents were censored at the time when the death occurred, and all the other participants were censored on 31 December 2016. The multivariate all-cause mortality analyses were completed using a Cox proportional hazards regression model with the PHREG procedure in SAS. Competing risk analyses were completed for each of the six specific causes of death using Cox models, in which the other causes were treated as censored at the time when the other causes occurred (one cause of death removes the individual from all the other causes) [31]. The proportional hazards assumption of each model was evaluated using the Schoenfeld residuals and found to be tenable.

Results

Descriptive and bivariate Analysis

After removal of those with complete recovery and those with missing data, 2979 participants remained, 1354 individuals from cohort 1 and 1625 from cohort 2. Of the first cohort enrolled in 1997–1998, 863 completed follow-up measures during 2007–2009. As of 31 December 2016, there were a total of 803 deaths (27%). The average follow-up was 5.11 years for the deceased and 8.90 years for those alive. The univariate Cox models (Table 1) indicated several demographic, injury, and behavioral characteristics were significantly associated with all-cause mortality. Specifically, the decedents were injured at older age (39 ± 16.30

Table 1 Participant characteristics and univariate Cox model results

	Survivors $N=2176$	Deceased $N=803$	p-value[a]
Mean ± SD			
Age at injury	31.53 ± 13.19	38.99 ± 16.30	<.01
Years post-injury	11.61 ± 9.24	13.41 ± 9.92	<.01
Column %			
Injury severity			
C1-C4, non-ambulatory	8	19	<.01 (ref = ambulatory)
C5-C8, non-ambulatory	24	31	<.01 (ref = ambulatory)
Non-cervical, non-ambulatory	35	35	<.01 (ref = ambulatory)
All ambulatory	32	16	
Race/Ethnicity			
Non-Hispanic White	71	71	0.59 (ref = others)
Non-Hispanic Black	21	20	0.63 (ref = others)
Others	9	9	
Sex			
Female	25	21	
Male	75	79	0.01 (ref = female)
Weight status			
Underweight	5	10	<.01 (ref = others)
Overweight	12	14	0.04 (ref = others)
Others	83	76	
Health behaviors			
Medication usage[b]	−0.29	0.79	<.01
Nutrition—1[b]	0.06	−0.17	0.17
Nutrition—2[b]	0.05	−0.14	0.01
Fitness[b]	0.33	−0.88	<.01
Alcohol[b]	0.05	−0.13	0.09
Smoking[b]	−0.16	0.44	<.01

[a]Univariate Cox models

[b]Standardized composite score

years old), were further post-injury (13.41 ± 9.92 years), and were more likely to be male, underweight or overweight, and more severely injured compared to those who were alive. Regarding health behaviors, the decedents reported using more prescription medications, more nutrition—2 eating practices, lower fitness levels, and smoking more than the survivors.

Multivariate results

The multivariate analyses for all-cause mortality (Table 2) indicated more severe injury, being male, age at injury onset, years post-injury, and being underweight were significantly associated with higher all-cause mortality. Further, we found higher prescription medication usage scores, higher smoking scores, and lower fitness levels were risk factors for all-cause mortality. The nutrition and alcohol factors were not statistically significant predictors of mortality.

Competing risks analyses

The results of the competing risk analyses for specific causes of death are presented in Table 3. Injury severity was a significant risk factor for each of the specific causes of death, except for cancer. As injury severity increased, the hazard of death due to sepsis, pneumonia and influenza, heart and blood vessel diseases, unintentional injuries, and all other causes increased. The associations were most evident for deaths caused by sepsis and pneumonia and influenza; compared with ambulatory participants, individuals with C1-C4 level injury were roughly five times more likely to die of sepsis (HR = 5.96; 95% CI 2.19–16.19) and pneumonia and influenza (HR = 6.22; 95% CI 2.39–16.18).

Table 2 Multivariate all-cause mortality results

	HR	95% CI	*p*-value
Injury severity (ref = ambulatory)			
C1-C4, non-ambulatory	3.87	3.05–4.92	<.0001
C5-C8, non-ambulatory	2.45	1.98–3.04	<.0001
Non-cervical, non-ambulatory	1.9	1.54–2.35	<.0001
Race/Ethnicity (ref = others)			
Non-Hispanic White	1.05	0.82–1.35	0.71
Non-Hispanic Black	1.01	0.76–1.34	0.96
Sex (ref = female)			
Male	1.24	1.04–1.49	0.02
Age at injury	1.05	1.04–1.06	<.0001
Years post-injury	1.05	1.04–1.05	<.0001
Weight status (ref = others)			
Underweight	1.41	1.09–1.81	0.01
Overweight	0.95	0.77–1.17	0.61
Health behaviors			
Medication usage[a]	1.08	1.06–1.11	<.0001
Nutrition—1[a]	0.99	0.97–1.01	0.33
Nutrition—2[a]	0.99	0.96–1.02	0.4
Fitness[a]	0.94	0.91–0.97	<.0001
Alcohol[a]	0.99	0.95–1.02	0.4
Smoking[a]	1.18	1.13–1.23	<.0001

HR hazard ratio, *CI* confidence interval

[a]Standardized composite score

Two age related factors, older age at injury onset and greater years post-injury, were significant risk factors for each of the causes except deaths due to unintentional injuries. Males were 86% more likely to have died of heart and blood vessel diseases and 38% more likely to have died from other causes. Being underweight was associated with a lower hazard of heart and blood vessel diseases (HR = 0.38; 95% CI [0.17–0.89]) but increased hazard of deaths due to cancer (HR = 2.10; 95% CI [1.00–4.45]) and other causes (HR = 1.77; 95% CI [1.25–2.50]). Individuals who were overweight had a significant, 123%, increased risk of death caused by sepsis (HR = 2.23; 95% CI [1.14–4.37]).

Examining the health behaviors, higher prescription medication usage was related to an increase in the hazard ratio of deaths caused by sepsis, unintentional injuries, and other causes of death. The nutrition—2 factor (mostly unhealthy eating practices factor) was negatively associated with deaths due to heart and blood vessel diseases (HR = 0.94; 95% CI [0.89–0.99]). Fitness level was significantly protective of deaths due to heart and blood vessel diseases and other causes. Alcohol was associated with an increased hazard of deaths due to unintentional injuries. Smoking was associated with increased risk of deaths due to cancer, heart and blood vessel diseases, and all other causes. The nutrition—1 factor (mostly healthy eating practices) was not associated with any of the causes of death.

Discussion

This study substantially enhances the literature by identifying competing risks for six *specific causes of death* using health behaviors as the primary predictors. It expands upon limited previous research on the relationships between health behaviors and mortality in SCI cohorts by further examining five of the leading causes of death [16–19]. These findings are particularly important because they link behaviors to specific causes of mortality and identify relationships between risk behaviors and mortality that may be concealed when looking only at all-cause mortality. For instance, binge drinking was not significantly related to all-cause mortality, yet was a significant predictor of unintentional injuries. Being underweight was a risk factor for one cause of death (cancer), yet protective of another cause of death (heart and blood). Clearly, this analysis is needed for targeting interventions to reduce cause-specific mortality.

There were several unique behavioral risk factors for specific causes of death. The risk of death due to sepsis was only increased in those who reported greater frequency of prescription medication usage for treating pain, spasticity, depression, and sleep problems. Deaths due to cancer were positively associated with a higher reported smoking score; there were no other significant health behavior risk factors. The hazard of death due to heart and blood vessel diseases was lower among those who reported better fitness and, surprisingly, those who reported higher scores on the nutrition—2 factor, which primarily reflects unhealthy eating behaviors like eating fried, fast food, or red meat and adding salt to food. This finding is somewhat conflicting but may be related to one of the individual variables included in the nutrition—2 factor, such as eating red meat, or it may reflect unknown socioeconomic factors (i.e., the ability to buy food and total caloric intake). It is also noteworthy that being underweight, rather than overweight, was a risk factor for all-cause mortality, further suggesting the importance of at least meeting minimum daily caloric intake needs. It also may reflect the statistical controls for other factors, such as weight status. Smoking increased the risk of death due to heart and blood vessel diseases. The risk of death due to unintentional injuries was increased among those who reported greater prescription medication usage and alcohol use. Interestingly, the risk profile for deaths due to *all other causes* mirrored that of all-cause mortality, with prescription medication usage and smoking increasing risk, and greater fitness level decreasing the risk of mortality. There were no significant relationships between health behaviors and risk of death due to pneumonia and influenza.

Table 3 Competing risks analyses for specific causes of death

	Sepsis			Pneumonia/Influenza			Cancer			Heart and blood vessel diseases			Unintentional injuries			All other causes		
	HR	95% CI	*p*-value	HR	95% CI	*p*-value	HR	95% CI	*p*-value	HR	95% CI	*p*-value	HR	95% CI	*p*-value	HR	95% CI	*p*-value
Injury severity (ref = ambulatory)																		
C1-C4, non-ambulatory	5.96	2.19–16.19	0.00	6.22	2.39–16.18	0.00	1.19	0.55–2.57	0.66	3.05	1.77–5.28	<.0001	2.41	1.13–5.16	0.02	5.69	3.94–8.23	<.0001
C5-C8, non-ambulatory	3.43	1.34–8.79	0.01	3.10	1.24–7.76	0.02	0.98	0.55–1.76	0.96	2.65	1.68–4.18	<.0001	1.60	0.83–3.09	0.16	3.26	2.32–4.59	<.0001
Non-cervical, non-ambulatory	2.51	0.99–6.40	0.05	1.60	0.61–4.18	0.34	0.81	0.47–1.41	0.46	2.12	1.36–3.30	0.00	1.58	0.85–2.96	0.15	2.50	1.78–3.51	<.0001
Race/Ethnicity (ref = others)																		
Non-Hispanic White	1.15	0.39–3.37	0.80	2.14	0.52–8.78	0.29	0.96	0.43–2.13	0.92	1.16	0.66–2.05	0.60	1.15	0.52–2.53	0.73	0.95	0.67–1.35	0.77
Non-Hispanic Black	2.41	0.77–7.51	0.13	2.76	0.63–12.16	0.18	1.07	0.44–2.61	0.88	1.36	0.74–2.52	0.32	0.53	0.19–1.47	0.22	0.75	0.50–1.14	0.18
Sex (ref = female)																		
Male	0.97	0.51–1.85	0.92	0.58	0.30–1.11	0.10	1.11	0.64–1.92	0.72	1.86	1.22–2.84	0.00	0.98	0.57–1.70	0.95	1.38	1.04–1.81	0.02
Age at injury	1.05	1.02–1.07	<.0001	1.06	1.04–1.09	<.0001	1.07	1.06–1.09	<.0001	1.06	1.05–1.07	<.0001	1.01	0.99–1.03	0.26	1.05	1.04–1.06	<.0001
Years Post-injury	1.08	1.05–1.11	<.0001	1.06	1.02–1.09	0.00	1.08	1.06–1.11	<.0001	1.06	1.04–1.08	<.0001	0.99	0.96–1.02	0.50	1.04	1.03–1.05	<.0001
Weight status (ref = others)																		
Underweight	1.34	0.45–3.96	0.60	1.64	0.55–4.86	0.37	2.10	1.00–4.45	0.05	0.38	0.17–0.89	0.03	1.86	0.89–3.91	0.10	1.77	1.25–2.50	0.00
Overweight	2.23	1.14–4.37	0.02	0.61	0.23–1.62	0.32	1.49	0.83–2.69	0.18	0.73	0.46–1.16	0.19	0.87	0.43–1.74	0.69	0.89	0.65–1.22	0.48
Health behaviors																		
Medication usage[a]	1.11	1.01–1.22	0.04	1.10	0.99–1.23	0.09	1.03	0.96–1.12	0.42	1.03	0.98–1.09	0.29	1.14	1.05–1.24	0.00	1.10	1.06–1.15	<.0001
Nutrition—1[a]	0.98	0.91–1.05	0.54	1.01	0.93–1.09	0.91	0.96	0.90–1.02	0.17	1.02	0.98–1.06	0.39	0.95	0.90–1.01	0.11	1.00	0.97–1.02	0.73
Nutrition—2[a]	1.03	0.93–1.14	0.59	1.01	0.90–1.12	0.90	1.07	0.98–1.16	0.12	0.94	0.89–0.99	0.03	1.01	0.93–1.10	0.75	0.98	0.95–1.02	0.36
Fitness[a]	0.99	0.89–1.10	0.89	0.96	0.86–1.08	0.49	0.97	0.89–1.06	0.47	0.87	0.82–0.92	<.0001	0.95	0.87–1.03	0.20	0.95	0.91–0.99	0.02
Alcohol[a]	0.89	0.75–1.06	0.19	0.86	0.70–1.07	0.18	0.97	0.88–1.08	0.62	0.96	0.89–1.04	0.34	1.10	1.01–1.19	0.02	0.99	0.94–1.04	0.66
Smoking[a]	1.13	0.96–1.33	0.15	1.10	0.92–1.32	0.31	1.17	1.03–1.34	0.02	1.17	1.07–1.29	0.00	1.13	0.99–1.28	0.06	1.20	1.13–1.28	<.0001

HR hazard ratio, *CI* confidence interval

[a]Standardized composite score

The results support previous findings that modifiable health behaviors such as prescription medication usage [11, 16–18, 26], smoking [17–19, 24, 25], and alcohol usage [11, 16–18] increase the risk of mortality after SCI, while nutrition and fitness level may be protective of mortality after SCI [17, 19]. There is relatively little literature examining how prescription medication usage, specifically opioid use contributes to increased risk of cause-specific mortality. Our finding that increased frequency of prescription medication use was associated with increased risk of death due to sepsis may be related to a phenomenon whereby individuals with more health complications take more prescription medications, or a complex and not yet fully understood relationship between opioid exposure, immune impairment, sepsis progression, and mortality. A recent study of hospitalized individuals with sepsis found that prescription opioids are associated with an increased risk of mortality [32]. Continued research is necessary to evaluate this relationship among those with SCI and further evaluate other classes of prescription medications and the related risk of sepsis deaths and all-cause mortality.

Considering these findings in conjunction with recently published data on health factors associated with specific causes of death [33], we may illuminate potential targets for future interventions to decrease the risk of cause-specific deaths after SCI. For instance, one health factor, pressure ulcers, was significantly related to all causes of death except pneumonia and influenza and cancer [33]. Looking specifically at the complex association with heart and blood vessel disease related death and the unexplained relationship with unintentional deaths, the current study provides some behavioral mechanisms by which pressure ulcers may be related to the specific causes of death. Smoking, for example, is a known risk factor for pressure ulcers and appears in the current analysis as a risk factor for cardiovascular related deaths. Smoking may be a behavior that influences the previously identified relationship between pressure ulcers and increased risk of heart and blood vessel disease deaths. Similarly, the current analysis supports previous research that binge drinking and medication usage, two factors associated with the risk of pressure ulcers [20, 34], are also associated with unintentional deaths [16].

The unique new information from this study is that it will allow those in multiple disciplines to apply proven interventions targeting specific behaviors *in combination* with specific diseases and conditions that are the leading causes of death after SCI. This is much more powerful than implementing interventions that simply apply globally to all-cause mortality. Notably, some risk factors for the specific causes of death are not related to all-cause mortality and would be missed without accounting for specific causes. The variety of health professionals addressing different health behaviors should not be underestimated. There are specialists in smoking cessation; nutritionists would address healthy eating; physical therapists promote exercise and fitness interventions. A multidisciplinary approach may be used to attenuate deaths within a particular category, such as deaths due to unintentional injuries, where there are multiple behavioral risk factors.

Study strengths and limitations

There are several important methodologic considerations, both strengths and weaknesses. First, we utilized prospective cohort methodology based on the TRPM. The prospective design and utilization of the conceptual model were significant strengths because the variables were specifically and systematically chosen for the association with mortality. Second, we utilized health behavior *factors* that were defined by previous latent structural modeling [27] and similar to those used in an earlier analysis [17]. The strengths are that it is based on previous research, and the variables are not being measured by a single variable (i.e., number of cigarettes per day). However, due to the use of health behavior *factors*, the translation is less direct. For instance, we did not analyze the risks of the specific variables independent of the factors under which they were grouped. Additional behaviors may be introduced into these domains or serve as alternatives (e.g., other types of foods or nutritional practices that would fall within 1 of the 2 nutritional domains). Third, we used a competing risk model. The independent identification of risk and protective factors for each cause of death is a strength; however, this reduces the power of the analysis to identify significant differences. We were restricted in the number of variables that could be evaluated in a given analysis. We focused on health behaviors, one level within the multistage TRPM. For the sake of model building, it is necessary to analyze sets of predictive factors one at a time in conjunction with basic statistical controls (demographic and injury characteristics). Ideally, we would focus on additional predictors from each level of the conceptual model.

Overall we had high response rates for both times of measurement, and we have longitudinal data for 863 participants who were enrolled in the first time of measurement. These findings are generalizable to those living in the community with chronic traumatic SCI.

Another important methodologic consideration is related to the classification of causes of death, which were chosen on an a priori basis. We chose categories that have the greatest potential risk of excess mortality after SCI. We had a large number of cases in the "other cause of death" category and hope to address this in future research by narrowing to specific causes. It is also possible to modify the classifications of death to include larger categories. For example, we focused on deaths due to unintentional injuries, rather than the broader category of external cause, which would include unintentional injuries, suicide, and homicide. By limiting the category, we draw more clear conclusions. Similarly, we focused on pneumonia and influenza, rather than the broader category of diseases of the respiratory system, and sepsis rather than the broader category of infectious and parasitic disease. While this helped interpretation of our analyses, it did result in a large "other causes of death" category that was related to several risk and protective behaviors which are difficult to interpret.

Future research

Continued research is warranted to better understand the modifiable risk and protective health behaviors of specific causes of death. There is a need for increasing sample size and study power, as well as investigation of a broader range of predictor variables. This includes the future analysis of health behaviors in addition to other sets of predictors (e.g., health factors) that may be associated with the specific causes of mortality. Additionally, a focused study of prescription medication use, by medication class, would greatly add to the current scope of knowledge. Because the behavioral data were collected in advance of mortality, some contribution to causality is highly probable, although causality cannot be proven with this design. The findings do have two clear implications: (1) they may be used to identify people at risk for cause-specific mortality, and (2) they may become the targets of intervention, such that a reduction in the behaviors associated with cause-specific mortality may reduce mortality due to these causes. Because these health behaviors are predictive of morbidity and mortality, it is important to more closely examine the relationships and mechanisms by which we may attenuate risk. These findings highlight specific areas for translation into rehabilitation research, specifically targeting behavioral change through intervention. There no doubt are additional variables which would contribute to our understanding of those factors leading to excess mortality. Future study of other levels of the TRPM (e.g., psychological factors) would help to provide a more complete picture of the factors influencing cause-specific mortality after SCI and enhance the ability of clinicians and researchers to tailor interventions for the multitude of predictors.

Conclusion

The findings confirm the importance of avoiding certain risk behaviors, such as medication misuse and smoking, to prevent increased risk of all-cause mortality, and highlight unique risk factors for specific causes of death. Taking these results into consideration with previous findings, this study affirms the importance of behavioral risk factors as targets for SCI rehabilitation interventions. Through continued research it will be possible to identify more specific behavioral risk factors related to cause-specific excess mortality and enhance our ability to identify individuals at high risk and implement individualized intervention strategies.

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Compliance with ethical standards

Statement of ethics We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research.

Conflict of interest The authors declare that they have no conflict of interest.

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